



Faculty of Manufacturing Engineering

**DEVELOPMENT OF KENAF WOVEN FABRIC REINFORCED
EPOXY AND POLYPROPYLENE COMPOSITE WITH DIFFERENT
STITCHING PATTERN**

Mohd Amirhafizan bin Hj. Husin

Doctor of Philosophy

2021

**DEVELOPMENT OF KENAF WOVEN FABRIC REINFORCED EPOXY AND
POLYPROPYLENE COMPOSITE WITH DIFFERENT STITCHING PATTERN**

MOHD AMIRHAFIZAN BIN HJ. HUSIN

**A thesis submitted
in fulfilment of the requirements for the degree of Doctor of Philosophy**

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

DECLARATION

I declare that this thesis entitled “Development of Kenaf Woven Fabric Reinforced Epoxy and Polypropylene Composite with Different Stitching Pattern” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : Mohd Amirhafizan bin Hj. Husin
.....

Date :

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature :

Supervisor Name : Associate Professor, Ir. Ts. Dr. Mohd Yuhazri bin Yaakob

Date :

DEDICATION

Every challenging work needs self-effort as well as guidance from the elders,
especially those who were very close to our hearts.

My humble effort I dedicate to,

My mother, Munah Bakar and late father, Husin Awang,
whose affection, love, encouragement and prayer,
day and night, make me capable of such success and honour.

My amazing and beautiful wife, Syuhazlein Mamad,
whose sacrificial care for me and our child, Uwais Al Qarni,
made it possible for me to complete this work.

My loving family,
whose always support me in completing this thesis.

ABSTRACT

Natural fibres, due to their eco-friendly nature and sustainability, receive attention from researchers and academics to be used in polymer composites. In this study, the effect of stitching pattern on properties of woven kenaf fabric reinforced polymer (thermoset and thermoplastic) composites was analysed. The hand lay-up followed by a vacuum baggage technique was used to fabricate thermoset composite and a hot pressing technique was used to produce thermoplastic composites. The materials used were epoxy resin and polypropylene, which acted as matrices and woven kenaf fibre as a reinforcement. The composites were made in different patterns of stitches which were divided into two categories, basic patterns which were stitched together by a single cross, including Vertical (V), Horizontal (H), Tilt 30° (T30) and Tilt 60° (T60). The other was a complex pattern, stitch with a double cross, including Box, Tilt 45°/90° (T45/90), Tilt 30°/30° (T30/30) and Tilt 60°/60° (T60/60). Tensile test, impact test and hemisphere test of the composites were evaluated in accordance with an ASTM standard. The highest specific strength for single and double stitching was found in samples V and T60/60 of 9.53 MPa/g and 12.75 MPa/g respectively, with an improvement of 14.41% and 53.06% compared to unstitched samples. It was also found that the double stitch patterns show good agreement in improving the tensile and impact performance, either for reinforced thermoset or thermoplastic composite. The results also show that the composite samples reinforced thermoset matrix have better specific strength performance, approximately 3.58 MPa/g to 10.49 MPa/g compared to the composite reinforced thermoplastic matrix. This is due to the thermosetting matrix is generally tougher and stronger than thermoplastics. However, in impact performance, thermoplastic reinforced composite samples show higher impact strength, approximately 3.73 J/cm² to 4.25 J/cm² compared to thermoset composites due to excellent impact resistance and damage tolerance by reducing crack propagation and better stress distribution throughout the structure. The evidence from this study suggested that the stitching patterns and stitching angle gave significant effect to the performance of woven stitch kenaf composite compared to the unstitched ones. Implications of the results and future research direction were also presented.

PEMBANGUNAN KOMPOSIT POLIPROPILENA DAN EPOKSI DIPERKUAT FABRIK TENUN KENAF DENGAN JENIS JAHITAN BERBEZA

ABSTRAK

Serat semula jadi, telah mendapat perhatian daripada penyelidik dan ahli akademik untuk digunakan dalam komposit polimer kerana sifat yang mesra alam dan kelestariannya. Dalam kajian ini, teknik jahitan pada tenunan kenaf yang diperkuat oleh polimer (termoset dan termoplastik) telah dianalisis. Proses bengkalai tangan dan diikuti oleh bungkusan vakum digunakan untuk komposit termoset, manakala teknik tekanan panas digunakan untuk komposit termoplastik. Bahan yang digunakan adalah resin epoksi dan polipropilena yang bertindak sebagai pengikat dan serat tenunan kenaf sebagai tetulang. Komposit dalam corak jahitan yang berbeza dibahagikan kepada dua kategori, iaitu corak asas yang dijahit tunggal termasuk Menegak (V), Melintang (H), Condong 30° (T30) dan Condong 60° (T60). Kedua ialah corak kompleks yang dijahit dengan arah berganda, termasuk Kotak, Condong 45°/90° (T45/90), Condong 30°/30° (T30/30) dan Condong 60°/60° (T60/60). Ujian tegangan, ujian impak dan ujian hemisfera telah dinilai mengikut piawaian ASTM. Kekuatan spesifik tertinggi untuk jahitan tunggal dan berganda ialah sampel V dan T60 / 60 masing-masing 9.53 MPa/g dan 12.75 MPa/g, dengan peningkatan 14.41% dan 53.06% berbanding dengan sampel yang tidak dijahit. Juga didapati bahawa corak jahitan berganda menunjukkan kesepakatan yang baik dalam meningkatkan prestasi tegangan dan hentaman, baik untuk termoset ataupun termoplastik komposit. Hasilnya juga menunjukkan bahawa sampel komposit yang diperkuatkan oleh termoset mempunyai prestasi kekuatan spesifik yang lebih baik, kira-kira 3.58 MPa/g hingga 10.49 MPa/g berbanding dengan pengikat termoplastik komposit. Ini disebabkan pengikat termoset pada umumnya lebih keras dan kuat berbanding dengan pengikat termoplastik. Walau bagaimanapun, dalam prestasi hentaman, sampel komposit diperkuatkan oleh termoplastik menunjukkan kekuatan hentaman yang lebih tinggi, kira-kira 3.73 J/cm² hingga 4.25 J/cm² berbanding komposit termoset kerana rintangan hentakan yang sangat baik dan toleransi kerosakan dengan mengurangkan penyebaran retakan dan pengedaran tegasan yang lebih baik di seluruh struktur. Bukti dari kajian ini menunjukkan bahawa corak jahitan dan sudut jahitan memberikan kesan yang signifikan terhadap prestasi komposit anyaman kenaf yang dijahit berbanding dengan yang tidak dijahit. Implikasi dari hasil dan arah kajian masa depan juga dikemukakan.

ACKNOWLEDGEMENTS

The author would like to recognize the financial support given by Skim Zamalah UTeM and Faculty of Mechanical and Manufacturing Engineering Technology Universiti Teknikal Malaysia Melaka (UTeM) due to permission given to use all the facilities in the Composites Engineering & Technology Laboratory.

Apart from that, it's very much appreciated to have an excellent supervisor Associate Professor Ir. Ts. Dr. Mohd Yuhazri Bin Yaakob from the Faculty of Mechanical and Manufacturing Engineering Technology UTeM. Not to forget, Professor Dato' Dr. Abu Bin Abdullah from Faculty of Manufacturing Engineering UTeM. Their essential supervision, support and encouragement to complete this thesis. In addition, assistance from Pak Ip and Saijod to make the project even successful.

Special thanks to all my colleagues, my beloved mother, late father and siblings for their moral support in completing this degree. Lastly, thank you to everyone who had been associated to the crucial parts of realization of this project.

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vii
LIST OF FIGURES	ix
LIST OF ABBREVIATIONS	xvii
LIST OF SYMBOLS	xix
LIST OF PUBLICATIONS	xxi
 CHAPTER	
1. INTRODUCTION	1
1.1 Background	1
1.2 Problem statement	3
1.3 Objectives	4
1.4 Scopes of research	4
1.5 Rationale of research	5
1.6 Thesis organization	6
 2. LITERATURE REVIEW	7
2.1 Introduction	7
2.2 Natural fibre	9
2.3 Kenaf plant	12
2.3.1 Kenaf fibre composite	15
2.4 Woven kenaf fabric	19
2.5 Stitching technique	23
2.5.1 Type of stitching	25
2.5.2 Stitching structure	28
2.5.3 Process of stitching	29
2.6 Polymer composites	30
2.6.1 Thermoset polymer in kenaf composites	31
2.6.2 Thermoplastic polymer in kenaf composites	33
2.6.3 Summary of polymer matrix	35
2.7 Manufacturing of thermoset polymer	35
2.8 Manufacturing of thermoplastic polymer	40
2.9 Mechanical testing on woven fabric	43
2.10 Hemispherical clamping test for woven fabric	44
2.11 Application of natural fibre composite	45
2.12 Summary	48
 3. METHODOLOGY	51
3.1 An overview of methodology	51
3.2 Raw material preparation	53

3.2.1	Kenaf fibre	53
3.2.2	Thermoset matrix	54
3.2.3	Thermoplastic matrix	54
3.2.4	Woven kenaf roving	56
3.2.5	Stitching design on woven kenaf fabric	57
3.3	Composite preparation	60
3.3.1	Thermoset composite preparation	60
3.3.2	Thermoplastic composite preparation	61
3.3.3	Cutting process	62
3.4	Mechanical testing	62
3.4.1	Tensile testing	63
3.4.2	Impact testing	63
3.4.3	Hemisphere pressure clamped test (3D stamping test)	64
3.4.4	Compression test	65
3.5	Scanning electron microscope	66
3.6	Propose potential application	66
3.6.1	Potential application for thermoset composite	66
3.6.2	Potential application for thermoplastic composite	68
4.	RESULT AND DISCUSSION	70
4.1	Characterization of stitching and unstitching woven kenaf fabric	70
4.1.1	Characterization of SWKF reinforced thermoset composite	72
4.1.2	Characterization of SWKF reinforced thermoplastic composite	75
4.1.3	Summary of characterization of stitching woven kenaf fabric	78
4.2	Mechanical properties performance of samples	79
4.2.1	Tensile performance of single stitch pattern reinforced thermoset	79
4.2.2	Tensile performance of double stitch pattern reinforced thermoset	83
4.2.3	Comparison of specific strength for single and double stitch composite reinforced thermoset	86
4.2.4	Tensile performance of single stitch pattern reinforced thermoplastic	88
4.2.5	Tensile performance of double stitch pattern reinforced thermoplastic	93
4.2.6	Comparison of tensile performance for single and double stitch composite reinforced thermoplastic	96
4.2.7	Summary of samples reinforced thermoplastic composite	97
4.2.8	Comparison of specific strength for composite sample reinforced thermoset and thermoplastic	99
4.2.9	Impact performance	102
4.2.10	Impact performance of single stitch pattern reinforced thermoset	102
4.2.11	Impact performance of double stitch pattern reinforced thermoset	104

4.2.12	Comparison of impact performance for single and double stitch pattern reinforced thermoset	106
4.2.13	Summary of impact performance for sample reinforced thermoset	108
4.2.14	Impact performance of single stitch pattern reinforced thermoplastic	109
4.2.15	Impact performance of double stitch pattern reinforced thermoplastic	111
4.2.16	Comparison of single and double stitch pattern reinforced thermoplastic	112
4.2.17	Summary of sample reinforced thermoplastic	114
4.2.18	Comparison of impact performance of composite sample reinforced thermoset and thermoplastic	115
4.2.19	Failure mode of single and double stitch reinforced thermoset composite under impact test	117
4.2.20	Failure mode of single and double stitch reinforced thermoplastic composite under impact test	119
4.2.21	Comparison of morphology for stitching woven kenaf fabric reinforced thermoset composite	120
4.2.22	Comparison of morphology for stitching woven kenaf fabric reinforced thermoplastic composite	123
4.2.23	Characterization of SWKF on hemisphere clamped test	125
4.3	Potential application	136
4.3.1	Potential application of composite sample reinforced thermoset	136
4.3.2	Potential application of composite sample reinforced thermoplastic	141
5.	CONCLUSION AND RECOMMENDATION	145
5.1	Conclusions	145
5.2	Recommendations	148
	REFERENCES	150
	APPENDICE	198

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Expected worldwide production volume averages of different NF (in million metric tons per year) (Yan et al., 2014; Yan et al., 2016)	10
2.2	Recorded work on kenaf fibres based composites	12
2.3	Chemical arrangement, moisture content and microfibrillar angle of plant fibre (Lampke et al., 2005)	13
2.4	Suppliers of kenaf fibres in the world	16
2.5	Mechanical properties of kenaf fibres by several of researchers	19
2.6	Reported work on woven kenaf composite	22
2.7	Mechanical properties of kenaf fibre of different polymers	32
2.8	Manufacturing technique used by researchers in composite	39
3.1	Properties of epoxy used	54
3.2	Properties of PP	55
3.3	Types of single and double stitch patterns	58
3.4	Specification of cotton fibre (Latif et al., 2018)	59
3.5	Testing standard for mechanical testing	63
4.1	Unstitching and stitching pattern on woven kenaf fabric	71
4.2	Properties of SWKF reinforced thermoset	74
4.3	Properties of SWKF reinforced thermoplastic	76

4.4	Properties of single stitch and unstitch composite reinforced thermoset	80
4.5	Properties of double stitch and unstitch composite reinforced thermoset	84
4.6	Properties of single stitch and unstitch composite reinforced thermoplastic	89
4.7	Properties of double stitch and unstitch composite reinforced thermoplastic	95
4.8	Impact strength and energy absorption of single stitch and unstitch composite reinforced thermoset	103
4.9	Impact strength and energy absorption of double stitch and unstitch composite reinforced thermoset	105
4.10	Impact strength and energy absorption of single stitch and unstitch composite reinforced thermoplastic	110
4.11	Impact strength and energy absorption of double stitch and unstitch composite reinforced thermoplastic	111
4.12	Summary hemisphere performance for all type of stitching patterns	133
4.13	Images from the results of the paintball panel and armour vest	144

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Classification of natural fibre (Jawaid and Khalil, 2011)	11
2.2	Microscale fibre bundle to nanoscale cellulose microfibril in kenaf stem, redraw from (Khalil et al., 2013)	14
2.3	Kenaf plants in Pasir Putih Kelantan, Malaysia	15
2.4	The SEM micrographs of the (a) untreated kenaf fibre and (b) treated kenaf fibre with 6% of sodium hydroxide, with permission (Yousif et al., 2012)	17
2.5	SEM micrographs on the cross-section of (a) untreated and (b) treated kenaf fibre with reinforcement of epoxy, with permission (Yousif et al., 2012)	18
2.6	The stitches with polyethylene-co-methacryline acid in the carbon fibre-epoxy composite, with permission (Yang et al., 2013)	24
2.7	The effect of stitch density on tensile strength, redraw from (Karahana et al., 2010)	24
2.8	The effect of stitch density on tensile strength modulus, redraw from (Karahana et al., 2010)	25
2.9	Type of stitching (a) diagonal, (b) diamond, (c) square and (d) vertical pattern, with permission (Suhaimi et al., 2018)	26

2.10	The puncture load in different type of stitching, with permission (Suhaimi et al., 2018)	26
2.11	The surface structure of the non-crimp fibre with chain stitched, with permission (Lee et al., 2007)	27
2.12	Structure of stitch density in multiple-layer woven fabric, with permission (Yi and Jianlian, 2006)	28
2.13	Schematic view of (a) modified lock stitch (b) on woven fibre composite, redraw from (Tan et al., 2010; Abtew et al., 2018)	29
2.14	Modified chain stitching on plain laminate CFRP, with permission (Zheng et al., 2012; Mouritz and Cox, 2000)	30
2.15	Compression moulding process to fabricate polymer composite, redraw from (Park and Lee, 2012)	36
2.16	Hand lay-up process, redraw from (Prabhakaran and Kumar, 2012)	37
2.17	Cycle of resin transfer moulding process, redraw from (Sánchez et al., 2006)	38
2.18	Schematic of vacuum bagging process, redraw from (Centea et al., 2015)	38
2.19	Flow chart of the optimal manufacturing process for kenaf fibre reinforced thermoplastic with polypropylene matrix	42
2.20	Load deflection curve of the sandwich laminates composite (Al-Shamary et al., 2016).	44
2.21	Door trim base material utilized by 60% of natural fibre, with permission (Bharath and Basavarajappa, 2016)	47

2.22	Kenaf battery tray used by Ford of Europe, redraw from (Reddy, 2017)	48
2.23	Illustration of research gap	50
3.1	Flow chart of methodology	52
3.2	(a) kenaf long fibre; (b) divided to the size of 4 to 5 mm (± 0.1) and (c) closed up picture of kenaf yarns	53
3.3	Epoxy matrix (a) auto-fix 1345-B (b) auto-Fix 1710-A	54
3.4	Polypropylene pallets	55
3.5	Plain weave	56
3.6	(a) loom frame and (b) weaving process	57
3.7	(a) plain weave (b) closed up picture of plain weave	57
3.8	Sewing machine	58
3.9	Types of stitching patterns (a) Vertical; (b) Tilt 60°; (c) Horizontal; (d) Tilt 30°; (e) Tilt 30°/30°; (f) Tilt 45°/90°; (g) Box; (h) Tilt 60°/60°	59
3.10	Example of stitched Tilt 60°/60° on woven kenaf fabric	59
3.11	Schematic diagram of vacuum bagging process	60
3.12	Schematic diagram of hot pressing process	61
3.13	The dimension of tensile testing sample (ASTM D3039)	63
3.14	Geometry of specimen	64
3.15	(a) Hemispheric test for SWKF; (b) experimental setup for hemispheric test (Rashidi and Milani, 2018)	65
3.16	Illustration of SWKF cutting line	67
3.17	Illustration process of helmet fabrication	68

3.18	Natural helmet composite	68
3.19	Paintball vest (a); front view (b); and back view (b) of paintball panel	69
4.1	Example of illustration of single stitch pattern on woven kenaf fabric	70
4.2	Weight of the unstitched and stitched woven kenaf fabric	72
4.3	Composite sample O (a); reinforced thermoset (b) cross section	74
4.4	Illustration of defect on sample O reinforced thermoset	75
4.5	Schematic illustration of defect on sample O reinforced thermoplastic	77
4.6	Schematic illustration of defect occurred on sample O reinforced thermoplastic	77
4.7	Tensile strength and Young's modulus of single stitch and unstitch composite reinforced thermoset	80
4.8	Morphology image of V sample	81
4.9	Specific strength of double stitch and unstitch composite reinforced thermoset	83
4.10	SEM image of H stitch	83
4.11	Tensile strength and Young's modulus of double stitch and unstitch composite reinforced thermoset	85
4.12	Specific strength of double stitch and unstitch composite reinforced thermoset	86
4.13	SEM image of T60/60stitch	86
4.14	Comparison of specific strength of composite samples	87

4.15	Tensile strength and Young's modulus of single stitch and unstitch composite reinforced thermoplastic	89
4.16	Specific strength of single stitch and unstitch composite reinforced thermoplastic	91
4.17	SEM image of V stitch sample	91
4.18	SEM image of H stitch sample	92
4.19	Schematic illustration of H sample failure at stitch line	92
4.20	Schematic illustration of tighter fibre on H sample	92
4.21	Tensile strength and Young's modulus of double stitched and unstitched composite reinforced thermoplastic	94
4.22	Specific strength of double stitch and unstitch composite reinforced thermoplastic	95
4.23	SEM image of Box sample	96
4.24	Comparison of specific strength for single and double stitch composite	97
4.25	Comparison of specific strength for composite sample reinforced thermoset and thermoplastic	101
4.26	Impact strength and energy absorption of single stitched and unstitched composite sample reinforced thermoset	103
4.27	Impact strength and energy absorption of double stitch and unstitch composite sample reinforced thermoset	105
4.28	Sample of T30/30 failure at stitch line	106
4.29	Impact strength and energy absorption of composite sample reinforced thermoset	107

4.30	Impact strength and energy absorption of single stitch and unstitch composite sample reinforced thermoplastic	110
4.31	Schematic illustration of V stitched composite sample	110
4.32	Impact strength and energy absorption of double stitch and unstitch composite sample reinforced thermoplastic	112
4.33	Impact strength and energy absorption of composite sample reinforced thermoplastic	113
4.34	Comparison of impact strength for composite sample reinforced thermoset and thermoplastic	116
4.35	Failure mode of O (a); V (b); T60 (c); T30 (d) and H (e) samples reinforced thermoset composite	118
4.36	Failure mode of Box (a); T30/30 (b); T45/90 (c) and T60/60 (d) samples reinforced thermoset composite	118
4.37	Failure mode of O (a); V (b); T60 (c); T30 (d) and H (e) samples reinforced thermoplastic composite	119
4.38	Failure mode of Box (a); T30/30 (b); T45/90 (c) and T60/60 (d) samples reinforced thermoplastic composite	120
4.39	SEM image of single stitching reinforced thermoset composite for (a) V stitched; (b) T60 stitched; (c) T30 stitched and (d) H stitched	121
4.40	SEM image of double stitching reinforced thermoset composite for (a) Box stitched; (b) T30/30 stitched; (c) T45/90 stitched and (d) T60/60 stitched	122

4.41	SEM image of single stitching reinforced thermoplastic composite for (a) V stitched; (b) T60 stitched; (c) T30 stitched and (d) H stitched	124
4.42	SEM image of double stitching reinforced thermoplastic composite for (a) Box stitched; (b) T30/30 stitched; (c) T45/90 stitched and (d) T60/60 stitched	125
4.43	The deformed of O sample fabric (a) overview (b) close up	126
4.44	The deformed of V stitched pattern (a) overview (b) close up	127
4.45	The deformed of T60 stitched pattern (a) overview (b) close up	128
4.46	The deformed of T30 stitched pattern (a) overview (b) close up	128
4.47	The deformed of H stitched pattern (a) overview (b) close up	129
4.48	The deformed of Box stitched pattern (a) overview (b) close up	130
4.49	The deformed of T30/30 stitched pattern (a) overview (b) close up	131
4.50	The deformed of T45/90 stitched pattern (a) overview (b) close up	132
4.51	The deformed of T60/60 stitched pattern (a) overview (b) close up	133
4.52	Maximum load of all stitching patterns of woven kenaf fabric	134
4.53	The NFH made of T60/60 stitched kenaf reinforced thermoset composite	137
4.54	Comparison of total energy absorbed of both full prototype products	138
4.55	SEM images of failure mechanism for NFH, (a) delamination between the layers of the woven kenaf; (b) natural fibre helmet sample; (c) matrix crack failure and (d) kenaf fibre break	140

4.56	Comparison of energy absorbed and impact strength for both helmets	141
4.57	Prototype of paintball vest made from T60/60 stitched woven kenaf reinforced thermoplastic matrix	142
4.58	Skin lesions due to paintball impacts (Sbicca and Hatch, 2012; Aboutaleb and Stetson, 2005)	143
4.59	Schematic illustration of testing arrangement	143

LIST OF ABBREVIATIONS

ASTM	-	American society for testing and materials
HDPE	-	High density polyethylene
LKTN	-	Lembaga kenaf and tembakau negara, Malaysia
MARDI	-	Malaysian agricultural research and development institute
MN	-	Montmorillonite nanoclay
MPOB	-	Malaysian palm oil board
MRB	-	Malaysian Rubber Board
NF	-	Natural fibre
NFH	-	Natural fibre helmet
NFRCs	-	Natural fibre reinforced composites
PBS	-	Polybutylene succinate resin
PEEK	-	Poly (ether ether ketone)
PHV/PBAT	-	Poly(hydroxybutyrate-co-valerate)/poly(butylene adipate -co-terephthalate)
PLA	-	Poly (lactic acid)
PP	-	Polypropylene
PU	-	Polyurethane
PVC/EVA	-	Poly (vinyl chloride)/ethylene vinyl acetate
RTM	-	Resin transfer moulding
SEM	-	Scanning electron microscope

SWKF	-	Stitching woven kenaf fabric
TCP	-	Tributyl citrate plasticized
UF	-	Urea formaldehyde
UP	-	Unsaturated polyester

LIST OF SYMBOLS

σ	-	Stress
mm	-	Millimetre
m	-	Meter
g	-	gram
g/cm ³	-	Gram per centimetre cube
wt. %	-	Weight percentage
%	-	Percentage
MPa	-	Mega pascal
Kg	-	Kilogram
G _c	-	Fracture toughness
cm ²	-	Centimetre square
cm	-	Centimetre
s	-	Second
h	-	Hour
rpm	-	Revolution
V	-	Voltage
Hz	-	Hertz
W	-	Watt
mPa.s	-	Millipascal-second
A	-	Ampere